P22.1 (a) up

(b) out of the page, since the charge is negative.

(c) no deflection

(d) into the page

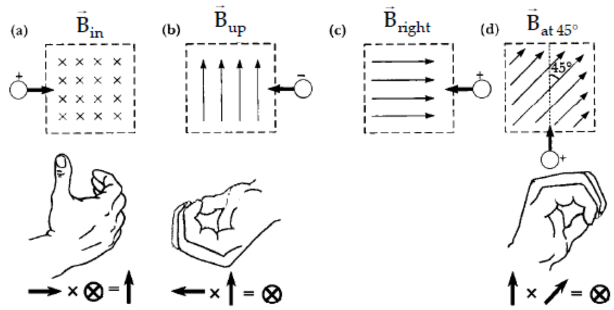


FIG. P22.1

***P22.2** At the equator, the Earth's magnetic field is horizontally north. Because an electron has negative charge, $\vec{F} = q\vec{v} \times \vec{B}$ is opposite in direction to $\vec{v} \times \vec{B}$. Figures are drawn looking down.

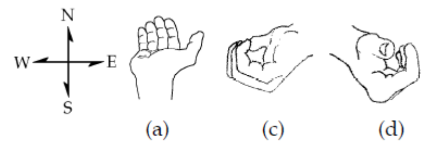


FIG. P22.2

(a) Down × North = East, so the force is directed $\boxed{\text{West}}$.

(b) North × North = $\sin 0° = 0$: $\boxed{\text{Zero deflection}}$.

(c) West × North = Down, so the force is directed $\boxed{\text{Up}}$.

(d) Southeast × North = Up, so the force is $\boxed{\text{Down}}$.

P22.3 (a) $F_B = qvB\sin\theta = \left(1.60\times10^{-19}\ \text{C}\right)\left(3.00\times10^{6}\ \text{m/s}\right)\left(3.00\times10^{-1}\ \text{T}\right)\sin 37.0°$

$F_B = \boxed{8.67\times10^{-14}\ \text{N}}$

(b) $a = \dfrac{F}{m} = \dfrac{8.67\times10^{-14}\ \text{N}}{1.67\times10^{-27}\ \text{kg}} = \boxed{5.19\times10^{13}\ \text{m/s}^2}$

P22.5 Gravitational force: $F_g = mg = \left(9.11\times10^{-31}\ \text{kg}\right)\left(9.80\ \text{m/s}^2\right) = \boxed{8.93\times10^{-30}\ \text{N down}}$.

Electric force: $F_e = qE = \left(-1.60\times10^{-19}\ \text{C}\right)\left(100\ \text{N/C down}\right) = \boxed{1.60\times10^{-17}\ \text{N up}}$.

Magnetic force: $\vec{F}_B = q\vec{v}\times\vec{B} = \left(-1.60\times10^{-19}\ \text{C}\right)\left(6.00\times10^{6}\ \text{m/s}\ \hat{\mathbf{E}}\right)\times\left(50.0\times10^{-6}\ \text{N}\cdot\text{s/C}\cdot\text{m}\ \hat{\mathbf{N}}\right)$.

$\vec{F}_B = -4.80\times10^{-17}\ \text{N up} = \boxed{4.80\times10^{-17}\ \text{N down}}$.

P22.6 $\vec{F}_B = q\vec{v}\times\vec{B}$

$$\vec{v}\times\vec{B} = \begin{vmatrix} \hat{\mathbf{i}} & \hat{\mathbf{j}} & \hat{\mathbf{k}} \\ +2 & -4 & +1 \\ +1 & +2 & -3 \end{vmatrix} = (12-2)\hat{\mathbf{i}} + (1+6)\hat{\mathbf{j}} + (4+4)\hat{\mathbf{k}} = 10\hat{\mathbf{i}} + 7\hat{\mathbf{j}} + 8\hat{\mathbf{k}}$$

$$\left|\vec{v}\times\vec{B}\right| = \sqrt{10^2+7^2+8^2} = 14.6\ \text{T}\cdot\text{m/s}$$

$$\left|\vec{F}_B\right| = q\left|\vec{v}\times\vec{B}\right| = \left(1.60\times10^{-19}\ \text{C}\right)\left(14.6\ \text{T}\cdot\text{m/s}\right) = \boxed{2.34\times10^{-18}\ \text{N}}$$

P22.9 $E=\frac{1}{2}mv^2=e\Delta V$

and $evB\sin 90°=\frac{mv^2}{R}$

$$B=\frac{mv}{eR}=\frac{m}{eR}\sqrt{\frac{2e\Delta V}{m}}=\frac{1}{R}\sqrt{\frac{2m\Delta V}{e}}$$

$$B=\frac{1}{5.80\times10^{10}\text{ m}}\sqrt{\frac{2\left(1.67\times10^{-27}\text{ kg}\right)\left(10.0\times10^{6}\text{ V}\right)}{1.60\times10^{-19}\text{ C}}}=\boxed{7.88\times10^{-12}\text{ T}}$$

P22.10 $F_B=F_e$

so $qvB=qE$

where $v=\sqrt{\frac{2K}{m}}$ and K is kinetic energy of the electron.

$$E=vB=\sqrt{\frac{2K}{m}}B=\sqrt{\frac{2(750)\left(1.60\times10^{-19}\right)}{9.11\times10^{-31}}}(0.015\,0)=\boxed{244\text{ kV/m}}$$

P22.11 In the velocity selector: $v=\frac{E}{B}=\frac{2\,500\text{ V/m}}{0.035\,0\text{ T}}=7.14\times10^{4}\text{ m/s}$.

In the deflection chamber: $r=\frac{mv}{qB}=\frac{\left(2.18\times10^{-26}\text{ kg}\right)\left(7.14\times10^{4}\text{ m/s}\right)}{\left(1.60\times10^{-19}\text{ C}\right)(0.035\,0\text{ T})}=\boxed{0.278\text{ m}}$.

P22.12 Note that the "cyclotron frequency" is an angular speed. The motion of the proton is described by $\sum F=ma$:

$$|q|vB\sin 90°=\frac{mv^2}{r}$$

$$|q|B=m\frac{v}{r}=m\omega$$

(a) $$\omega=\frac{|q|B}{m}=\frac{\left(1.60\times10^{-19}\text{ C}\right)(0.8\text{ N}\cdot\text{s/C}\cdot\text{m})}{\left(1.67\times10^{-27}\text{ kg}\right)}\left(\frac{\text{kg}\cdot\text{m}}{\text{N}\cdot\text{s}^2}\right)=\boxed{7.66\times10^{7}\text{ rad/s}}$$

(b) $$v=\omega r=\left(7.66\times10^{7}\text{ rad/s}\right)(0.350\text{ m})\left(\frac{1}{1\text{ rad}}\right)=\boxed{2.68\times10^{7}\text{ m/s}}$$

(c) $$K=\frac{1}{2}mv^2=\frac{1}{2}\left(1.67\times10^{-27}\text{ kg}\right)\left(2.68\times10^{7}\text{ m/s}\right)^2\left(\frac{1\text{ eV}}{1.6\times10^{-19}\text{ J}}\right)=\boxed{3.76\times10^{6}\text{ eV}}$$

(d) The proton gains 600 eV twice during each revolution, so the number of revolutions is

$$\frac{3.76\times10^{6}\ \text{eV}}{2(600\ \text{eV})}=\boxed{3.13\times10^{3}\ \text{revolutions}}.$$

(e) $\theta=\omega t$ $$t=\frac{\theta}{\omega}=\frac{3.13\times10^{3}\ \text{rev}}{7.66\times10^{7}\ \text{rad/s}}\left(\frac{2\pi\,\text{rad}}{1\ \text{rev}}\right)=\boxed{2.57\times10^{-4}\ \text{s}}$$

P22.15 $$\vec{\mathbf{F}}_B=I\vec{\ell}\times\vec{\mathbf{B}}=(2.40\ \text{A})(0.750\ \text{m})\hat{\mathbf{i}}\times(1.60\ \text{T})\hat{\mathbf{k}}=\boxed{\left(-2.88\hat{\mathbf{j}}\right)\ \text{N}}$$

P22.16 (a) $$F_B=ILB\sin\theta=(5.00\ \text{A})(2.80\ \text{m})(0.390\ \text{T})\sin60.0°=\boxed{4.73\ \text{N}}$$

(b) $$F_B=(5.00\ \text{A})(2.80\ \text{m})(0.390\ \text{T})\sin90.0°=\boxed{5.46\ \text{N}}$$

(c) $$F_B=(5.00\ \text{A})(2.80\ \text{m})(0.390\ \text{T})\sin120°=\boxed{4.73\ \text{N}}$$

P22.19 (a) $2\pi r=2.00\ \text{m}$

so $r=0.318\ \text{m}$

$$\mu=IA=\left(17.0\times10^{-3}\ \text{A}\right)\left[\pi(0.318)^2\ \text{m}^2\right]=\boxed{5.41\ \text{mA}\cdot\text{m}^2}$$

(b) $\vec{\boldsymbol{\tau}}=\vec{\boldsymbol{\mu}}\times\vec{\mathbf{B}}$

so $$\tau=\left(5.41\times10^{-3}\ \text{A}\cdot\text{m}^2\right)(0.800\ \text{T})=\boxed{4.33\ \text{mN}\cdot\text{m}}$$

P22.21 $\tau=NBAI\sin\phi$

$\tau=100(0.800\ \text{T})\left(0.400\times0.300\ \text{m}^2\right)(1.20\ \text{A})\sin60°$

$\tau=\boxed{9.98\ \text{N}\cdot\text{m}}$

Note that ϕ is the angle between the magnetic moment and the $\vec{\mathbf{B}}$ field. The loop will rotate so as to align the magnetic moment with the $\vec{\mathbf{B}}$ field. Looking down along the y-axis, the loop will rotate in a $\boxed{\text{clockwise}}$ direction.

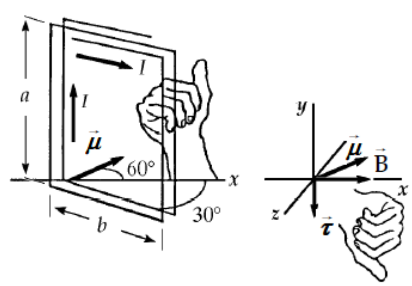


FIG. P22.21

P22.24 $$B=\frac{\mu_0 I}{2\pi R}=\frac{\left(4\pi\times10^{-7}\ \text{T}\cdot\text{m/A}\right)\left(1.00\times10^{4}\ \text{A}\right)}{2\pi(100\ \text{m})}=2.00\times10^{-5}\ \text{T}=\boxed{20.0\ \mu\text{T}}$$

P22.26 $$B=\frac{\mu_0 I}{2\pi r}=\frac{\left(4\pi\times10^{-7}\right)(1.00\ \text{A})}{2\pi(1.00\ \text{m})}=\boxed{2.00\times10^{-7}\ \text{T}}$$

P22.34 Let both wires carry current in the x direction, the first at $y = 0$ and the second at $y = 10.0$ cm.

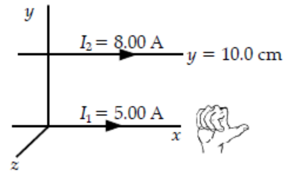


FIG. P22.34(a)

(a) $$\vec{B} = \frac{\mu_0 I}{2\pi r}\hat{k} = \frac{(4\pi\times10^{-7}\ \text{T}\cdot\text{m/A})(5.00\ \text{A})}{2\pi(0.100\ \text{m})}\hat{k}$$

$$\vec{B} = \boxed{1.00\times10^{-5}\ \text{T out of the page}}$$

(b) $$\vec{F}_B = I_2\vec{\ell}\times\vec{B} = (8.00\ \text{A})\left[(1.00\ \text{m})\hat{i}\times\left(1.00\times10^{-5}\ \text{T}\right)\hat{k}\right] = \left(8.00\times10^{-5}\ \text{N}\right)\left(-\hat{j}\right)$$

$$\boxed{\vec{F}_B = 8.00\times10^{-5}\ \text{N toward the first wire}}$$

(c) $$\vec{B} = \frac{\mu_0 I}{2\pi r}\left(-\hat{k}\right) = \frac{(4\pi\times10^{-7}\ \text{T}\cdot\text{m/A})(8.00\ \text{A})}{2\pi(0.100\ \text{m})}\left(-\hat{k}\right) = \left(1.60\times10^{-5}\ \text{T}\right)\left(-\hat{k}\right)$$

$$\vec{B} = \boxed{1.60\times10^{-5}\ \text{T into the page}}$$

(d) $$\vec{F}_B = I_1\vec{\ell}\times\vec{B} = (5.00\ \text{A})\left[(1.00\ \text{m})\hat{i}\times\left(1.60\times10^{-5}\ \text{T}\right)\left(-\hat{k}\right)\right] = \left(8.00\times10^{-5}\ \text{N}\right)\left(+\hat{j}\right)$$

$$\vec{F}_B = \boxed{8.00\times10^{-5}\ \text{N towards the second wire}}$$

P22.35 By symmetry, we note that the magnetic forces on the top and bottom segments of the rectangle cancel. The net force on the vertical segments of the rectangle is (using Equation 22.27)

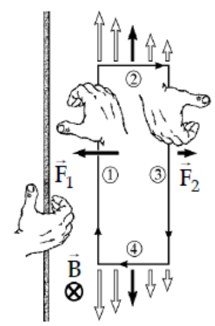


FIG. P22.35

$$\vec{F} = \vec{F}_1 + \vec{F}_2 = \frac{\mu_0 I_1 I_2 \ell}{2\pi}\left(\frac{1}{c+a} - \frac{1}{c}\right)\hat{i} = \frac{\mu_0 I_1 I_2 \ell}{2\pi}\left(\frac{-a}{c(c+a)}\right)\hat{i}$$

$$\vec{F} = \frac{(4\pi\times10^{-7}\ \text{N/A}^2)(5.00\ \text{A})(10.0\ \text{A})(0.450\ \text{m})}{2\pi}\left(\frac{-0.150\ \text{m}}{(0.100\ \text{m})(0.250\ \text{m})}\right)\hat{i}$$

$$\vec{F} = \left(-2.70\times10^{-5}\,\hat{i}\right)\text{N}$$

or $$\vec{F} = \boxed{2.70\times10^{-5}\ \text{N toward the left}}.$$

***P22.36** Carrying oppositely directed currents, wires 1 and 2 repel each other. If wire 3 were between them, it would have to repel either 1 or 2, so the force on that wire could not be zero. If wire 3 were to the right of wire 2, it would feel a larger force exerted by 2 than that exerted by 1, so the total force on 3 could not be zero. Therefore wire 3 must be to the left of both other wires as shown. It must carry downward current so that it can attract wire 2.

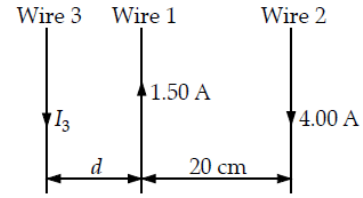


FIG. P22.36

(a) For the equilibrium of wire 3 we have

$$F_{1\text{ on }3} = F_{2\text{ on }3} \qquad \frac{\mu_0(1.50\text{ A})I_3}{2\pi d} = \frac{\mu_0(4\text{ A})I_3}{2\pi(20\text{ cm}+d)}$$

$$1.5(20\text{ cm}+d) = 4d \qquad d = \frac{30\text{ cm}}{2.5} = \boxed{12.0\text{ cm to the left of wire 1}}.$$

(b) For the equilibrium of wire 1,

$$\frac{\mu_0 I_3(1.5\text{ A})}{2\pi(12\text{ cm})} = \frac{\mu_0(4\text{ A})(1.5\text{ A})}{2\pi(20\text{ cm})} \qquad I_3 = \frac{12}{20}4\text{ A} = \boxed{2.40\text{ A down}}.$$

We know that wire 2 must be in equilibrium because the forces on it are equal in magnitude to the forces that it exerts on wires 1 and 3, which are equal because they both balance the equal-magnitude forces that 1 exerts on 3 and that 3 exerts on 1.

***P22.44** The field produced by the solenoid in its interior is given by

$$\vec{B} = \mu_0 nI(-\hat{i}) = (4\pi\times10^{-7}\text{ T}\cdot\text{m/A})\left(\frac{30.0}{10^{-2}\text{ m}}\right)(15.0\text{ A})(-\hat{i})$$

$$\vec{B} = -(5.65\times10^{-2}\text{ T})\hat{i}$$ 

The force exerted on side AB of the square current loop is

$$(\vec{F}_B)_{AB} = I\vec{\ell}\times\vec{B} = (0.200\text{ A})\left[(2.00\times10^{-2}\text{ m})\hat{j}\times(5.65\times10^{-2}\text{ T})(-\hat{i})\right]$$

$$(\vec{F}_B)_{AB} = (2.26\times10^{-4}\text{ N})\hat{k}$$ 

Similarly, each side of the square loop experiences a force, lying in the plane of the loop, of $\boxed{226\ \mu\text{N directed away from the center}}$. From the above result, it is seen that the net torque exerted on the square loop by the field of the solenoid should be zero. More formally, the magnetic dipole moment of the square loop is given by

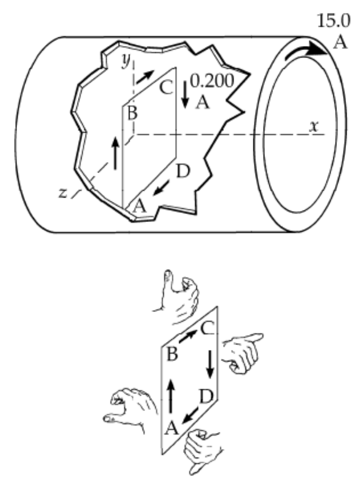


FIG. P22.44

$$\vec{\mu} = I\vec{A} = (0.200\text{ A})(2.00\times10^{-2}\text{ m})^2(-\hat{i}) = -80.0\ \mu\text{A}\cdot\text{m}^2\hat{i}$$ 

The torque exerted on the loop is then $\vec{\tau} = \vec{\mu}\times\vec{B} = (-80.0\ \mu\text{A}\cdot\text{m}^2\hat{i})\times(-5.65\times10^{-2}\text{ T}\hat{i}) = \boxed{0}$

P22.45 $$B = \mu_0\frac{N}{\ell}I \text{ so } I = \frac{B}{\mu_0 n} = \frac{(1.00\times10^{-4}\text{ T})0.400\text{ m}}{(4\pi\times10^{-7}\text{ T}\cdot\text{m/A})1\,000} = \boxed{31.8\text{ mA}}$$

P22.56 $\sum F_y = 0$: $+n - mg = 0$

$\sum F_x = 0$: $-\mu_k n + IBd\sin 90.0° = 0$

$$B = \frac{\mu_k mg}{Id} = \frac{0.100(0.200\text{ kg})(9.80\text{ m/s}^2)}{(10.0\text{ A})(0.500\text{ m})} = \boxed{39.2\text{ mT}}$$

P22.57 (a) The net force is the Lorentz force given by

$$\vec{\mathbf{F}} = q\vec{\mathbf{E}} + q\vec{\mathbf{v}} \times \vec{\mathbf{B}} = q\left(\vec{\mathbf{E}} + \vec{\mathbf{v}} \times \vec{\mathbf{B}}\right)$$

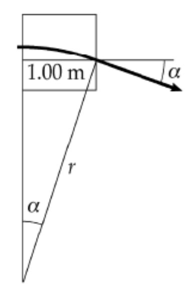
$$\vec{\mathbf{F}} = \left(3.20 \times 10^{-19}\right)\left[\left(4\hat{\mathbf{i}} - 1\hat{\mathbf{j}} - 2\hat{\mathbf{k}}\right) + \left(2\hat{\mathbf{i}} + 3\hat{\mathbf{j}} - 1\hat{\mathbf{k}}\right) \times \left(2\hat{\mathbf{i}} + 4\hat{\mathbf{j}} + 1\hat{\mathbf{k}}\right)\right]\text{ N}$$

Carrying out the indicated operations, we find:

$$\vec{\mathbf{F}} = \boxed{\left(3.52\hat{\mathbf{i}} - 1.60\hat{\mathbf{j}}\right) \times 10^{-18}\text{ N}}.$$

(b) $$\theta = \cos^{-1}\left(\frac{F_x}{F}\right) = \cos^{-1}\left(\frac{3.52}{\sqrt{(3.52)^2 + (1.60)^2}}\right) = \boxed{24.4°}$$

P22.58 The magnetic force on each proton, $\vec{\mathbf{F}}_B = q\vec{\mathbf{v}} \times \vec{\mathbf{B}} = qvB\sin 90°$ downward perpendicular to velocity, causes centripetal acceleration, guiding it into a circular path of radius r, with



$$qvB = \frac{mv^2}{r}$$

and $$r = \frac{mv}{qB}.$$

We compute this radius by first finding the proton's speed:

$$K = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2K}{m}} = \sqrt{\frac{2\left(5.00 \times 10^6\text{ eV}\right)\left(1.60 \times 10^{-19}\text{ J/eV}\right)}{1.67 \times 10^{-27}\text{ kg}}} = 3.10 \times 10^7\text{ m/s}.$$

Now, $$r = \frac{mv}{qB} = \frac{\left(1.67 \times 10^{-27}\text{ kg}\right)\left(3.10 \times 10^7\text{ m/s}\right)}{\left(1.60 \times 10^{-19}\text{ C}\right)\left(0.050\,0\text{ N}\cdot\text{s/C}\cdot\text{m}\right)} = 6.46\text{ m}.$$

(b) From the figure, observe that

$$\sin\alpha = \frac{1.00\text{ m}}{r} = \frac{1\text{ m}}{6.46\text{ m}}$$

$$\boxed{\alpha = 8.90°}$$

(a) The magnitude of the proton momentum stays constant, and its final y component is

$$-\left(1.67 \times 10^{-27}\text{ kg}\right)\left(3.10 \times 10^7\text{ m/s}\right)\sin 8.90° = \boxed{-8.00 \times 10^{-21}\text{ kg}\cdot\text{m/s}}.$$

P22.61 Let v_x and $v_\perp$ be the components of the velocity of the positron parallel to and perpendicular to the direction of the magnetic field.

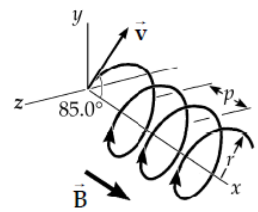


FIG. P22.61

(a) The pitch of trajectory is the distance moved along x by the positron during each period, T

$$p = v_x T = (v\cos 85.0°)\left(\frac{2\pi m}{Bq}\right)$$

$$p = \frac{\left(5.00\times10^{6}\right)(\cos 85.0°)(2\pi)\left(9.11\times10^{-31}\right)}{0.150\left(1.60\times10^{-19}\right)} = \boxed{1.04\times10^{-4}\text{ m}}$$

(b) From Equation 22.3,

$$r = \frac{mv_\perp}{Bq} = \frac{mv\sin 85.0°}{Bq}$$

$$r = \frac{\left(9.11\times10^{-31}\right)\left(5.00\times10^{6}\right)(\sin 85.0°)}{(0.150)\left(1.60\times10^{-19}\right)} = \boxed{1.89\times10^{-4}\text{ m}}$$